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Age estimation from pulp/tooth area ratio (PTR) in an Indian sample: A preliminary comparison of three mandibular teeth used alone and in combination[☆]

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ABSTRACT

Pulp/tooth area ratio (PTR) method of adult dental age estimation has been examined on few tooth types. We assessed the lateral incisor (LI) and first premolar (PM1) in addition to canine (C) — alone and in combination. Periapical radiographs from 61 Indians aged 21–71 years were examined. PTR of LI produced the best age correlation ($r = -0.395$) followed closely by PM1 ($r = -0.362$). The canine revealed the lowest correlation ($r = -0.206$); among tooth combinations, the three teeth taken together had the best R value (−0.438) followed by LI + PM1 (−0.435), LI + C (−0.406) and C + PM1 (−0.37). The standard errors of estimates (S.E.E.) of the regression analyses for the individual teeth and tooth combinations ranged from ±12.13 to 13.08 years, indicating minimal difference in age estimates using solitary or multiple teeth. Errors were higher than in European groups (±2.5–5 years) which may partly owe to moderate age correlation of secondary dentine deposition in Indians. Moreover, facial soft-tissue superimposition in living subjects evaluated herein possibly precluded optimal tooth and pulp canal visualization. These indicate that the PTR method should be used judiciously in age estimation of living Indian adults, although further studies on larger samples with evenly distributed age-groups is necessary for deriving definitive conclusions.

1. Introduction

Forensic age estimation is important in clarifying issues pertaining to unknown or disputed ages of living individuals as well as reconstructive identification of the deceased. The teeth are considered a reliable indicator of age and provide a number of parameters for age prediction, and traditional methods of adult dental age estimation require tooth extraction and processing.[1] While extracting normal healthy teeth, unless indicated, is unethical and not practical in living individuals, it may not be permitted even in the deceased when preservation of human remains is deemed essential for a variety of legal and cultural reasons; on the other hand tooth processing has the added disadvantage that it necessitates destruction of dental evidentiary material.

Radiographic evaluation of teeth requires neither tooth extraction nor processing; in post-mortem scenarios, teeth can easily be radiographed using apparatus readily available in most mortuary settings. Importantly, dental radiography is also applicable to the living owing to miniscule radiation exposure. These reasons prompted the development of dental radiographic methods for adult age estimation. Researchers have focused on the changes occurring within the pulp cavity and measuring the alterations — specifically, the deposition of secondary dentine — on radiographs for almost four decades.[2–5] However, these studies examined radiographs of tooth sections or intact extracted teeth and did not analyze X-rays taken in situ. Kvaal et al.[6] appear to be the first who evaluated radiographs obtained in situ, and also included secondary dentinal deposition within the root canal. While these authors[6] and others[7] measured the changes unidimensionally, later researchers used two- and three-dimensional methods to quantify reduction in the pulp chamber and root canal.[8–10]

One of these methods calculated the pulp/tooth area ratio (PTR) of maxillary canine and correlated this to age.[8] The method has elicited more interest than others and has been tested on different teeth,[11–14]

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large sample sizes,[15,16] and diverse populations.[14–16] An advantage of the method is that it calculates changes in tooth and pulp *area*, which may be more representative of alterations within teeth than one-dimensional length and width measurements undertaken by Kvaal et al.[6]; area is also more easily calculated and less equipment-intensive than computing pulp and tooth volumes.[9,10]

Calculation of the PTR, however, has so far been tested on a limited number of tooth types, namely maxillary canine,[8,12,13,15,17] mandibular canine,[12,13,15,16] maxillary incisors,[14] and mandibular second molar.[11] Also, the method's application on multiple teeth has been confined to the assessment of teeth from the same class, namely maxillary and mandibular canines.[12,15,18]

We recently assessed PTR in mandibular canines of Indians,[16] but obtained relatively poor age correlation as well as large errors in the age estimates. One possible approach to improving age prediction is to use multiple teeth and multiple regression models. A 'natural' improvement in age correlation and prediction may be expected using multiple teeth, as has been suggested and observed by at least one prominent author (p. 118)[1]; moreover, some studies that examined secondary dentinal deposition on radiographs, in particular, observed better age correlations (i.e., higher r/r^2 values) and superior age estimates (i.e., lower standard errors of estimate, S.E.E.) using mandibular lateral incisor, canines and first premolar *together* rather than in isolation.[6,19] Also, Cameriere et al.[12,13] assessed PTR on maxillary and mandibular canines and found higher correlation to age as well as better age estimates when both teeth were used in combination. Furthermore, these authors stated that future studies "should aim at acquiring data about other teeth" (p. 1155),[13] as well as investigate "the use of several teeth together" (p. 128.e5).[15] Since both lateral incisor and first premolar were visible on some of the canine radiographs taken by us previously,[16] we ventured to assess the use of the PTR of these two teeth in age estimation with a two-fold objective: (a) to determine its correlation to age and accuracy in age estimation vis-à-vis canine, and (b) to ascertain if the use of PTR of multiple teeth, particularly of different classes, enhanced age prediction accuracy.

2. Materials and methods

From our original sample of 178 radiographs,[16] all three teeth, viz., lateral incisors (LI), canines (C) and first premolars (PM1), were clearly visible on 61 (39 males and 22 females). Subjects' age ranged between 21 and 71 years and was relatively well distributed across the different age-groups (Table 1). Radiographs of the teeth (either left or right side) were made using the paralleling technique.

Details of measuring the pulp and tooth areas may be found in Babshet et al.,[16] who made minor modifications to the method put forth by Cameriere et al.[8] Briefly, radiographs were saved as high-resolution JPEG files on a computer and imported to Adobe Photoshop CS2 image-editing software program (Adobe Systems Inc., Mountain View, CA, USA) wherein the teeth's long axes were aligned vertically using the measure tool. A number of horizontal reference lines were marked at specific intervals along the length of the tooth, after which the images were once again saved as high-resolution JPEG files. Next, on an AutoCAD 2004 software program (Autodesk Inc., San Rafael, CA, USA), the pulp and tooth areas were measured using the point and line tools on the Draw toolbox and the pulp/tooth area ratio (PTR) calculated (Fig. 1).

Table 1
Sample distribution across age-groups and sexes.

Age-group (years)	Males	Females	Total
21–30	9	8	17
31–40	13	5	18
41–50	4	4	8
51–60	7	4	11
>60	6	1	7
Total	39	22	61

Ratios derived from the various teeth were subjected to linear (single tooth) and multiple (tooth combinations) regression analysis using SPSS 17.0 statistical package (SPSS Inc., Chicago, IL, USA). The regression correlation coefficients for single (r) and multiple teeth (R) were compared to ascertain which of them had a better relationship with age; the S.E.E. was calculated to gauge the deviation of the estimated age from the actual age which, in turn, reflects the accuracy of age prediction, as suggested by Liversidge et al (p. 26).[20]

To assess potential intra-observer variation, tooth and pulp areas of the lateral incisor and first premolar were re-measured on 25 randomly selected radiographs by the primary examiner (MB) after a period of approximately two months. The same radiographs were also examined by a second examiner (ABA) to evaluate potential inter-observer error. Values obtained were subjected to a paired t-test to ascertain if significant observer variation existed. Intra- and inter-observer differences in measuring the canine tooth and pulp areas have been assessed by us before.[16]

3. Results

The paired t-test to evaluate potential observer error revealed statistically significant intra-observer differences in lateral incisor and first premolar measurements ($p < 0.05$); significant differences were also found in the measurements taken by the second examiner on the premolar ($p < 0.05$), however, no statistical inter-observer differences were seen in measurements obtained on the lateral incisors ($p = 0.81$).

The regression correlation coefficients, the S.E.E., and the regression equations derived for individual teeth as well as different tooth combinations are presented in Table 2. Among the teeth assessed, the three-tooth combination produced the highest correlation coefficient ($R = -0.438$), followed closely by the LI + PM1 combination ($R = -0.435$), LI + C combination ($R = -0.406$) and the LI taken alone ($r = -0.395$). The first premolar taken alone ($r = -0.362$) and in combination with canine ($R = -0.37$) produced lower age correlations. The PTR of canine taken alone was found to have an r value of -0.206, rendering it with the poorest age correlation. Overall, all individual teeth/tooth combinations had low-to-moderate, albeit statistically significant, correlation to age ($p < 0.05$), the exception being the canine taken alone ($p = 0.11$). The errors of age estimation for the regression equations of various individual teeth/tooth combinations did not reveal any recognizable differences, with all of them producing S.E.E.s between ~12–13 years (Table 2).

4. Discussion

In the last decade, a number of new methods for age assessment from teeth have been developed,[21,22] or existing methods refined,[23–25] all of which claim relatively precise estimates. One major drawback of these methods, however, is the need to extract and process teeth, precluding their use in living subjects as well as in jurisdictions that do not permit post-mortem tooth extraction for a variety of legal and cultural reasons. Therefore, techniques that circumvent this limitation have also been developed, most prominent among which are radiographic and computerized tomography-based methods,[6,8–10] which can be applied both in the living and the deceased. The pulp/tooth area ratio method developed by Cameriere et al.[8] has been tested on contemporary subjects[8] and skeletonized human remains,[13,17] on different

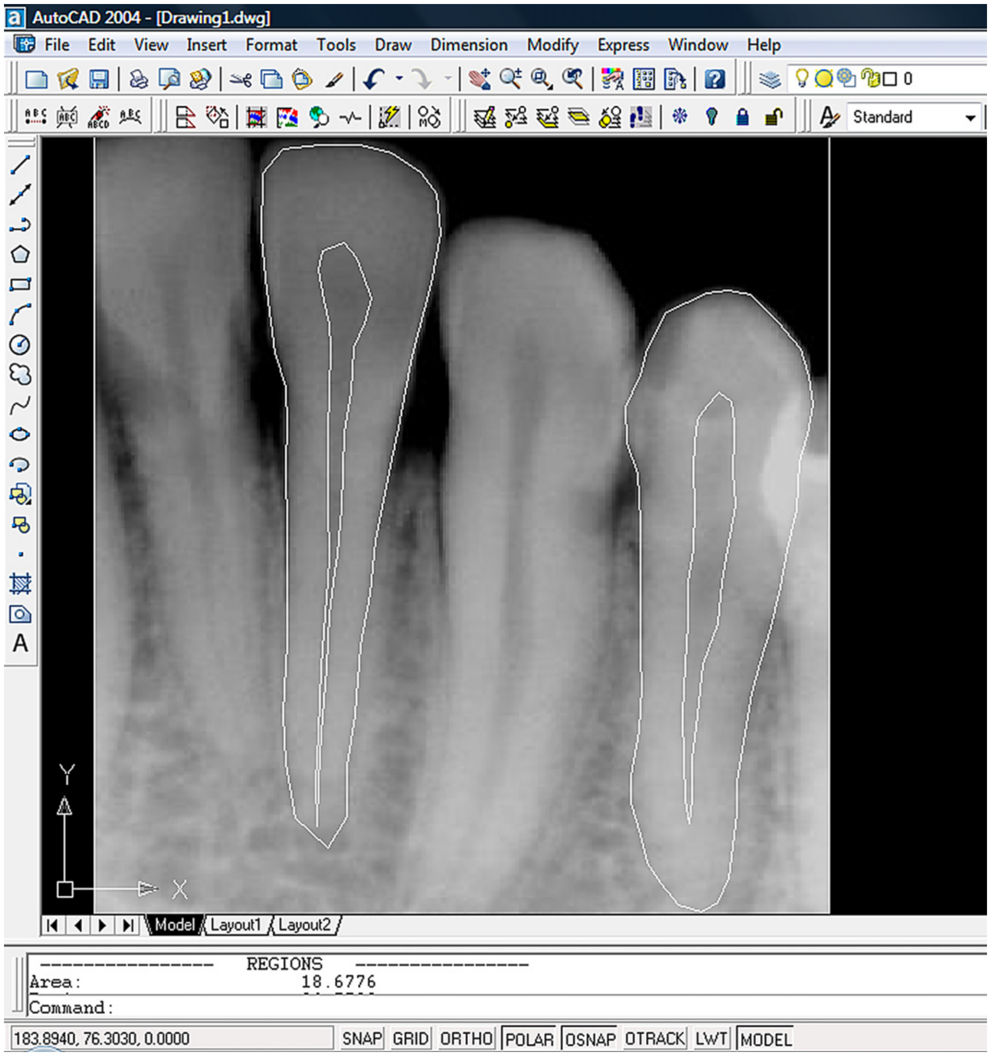

Fig. 1. The lateral incisor and first premolar as well as their pulp are shown delineated. This was accomplished first by manually defining the pulp and tooth outlines using the point and line tools on the AutoCad software program's Draw Toolbox; the areas of the outlined pulp and tooth were then calculated on the same software.

teeth[11,12,14] and populations,[14–16] and has mostly yielded accurate age estimates.

However, the method was untested on diverse classes of teeth and we undertook such an exercise primarily to determine if use of multiple tooth classes improved age assessment, particularly since the use of canines alone had resulted in errors > ±10 years in our sample previously[16] — an error rate which falls outside the "acceptable" range proposed by Solheim and Sundnes[26]; also, since the correlation of PTR of lateral incisor and first premolar was unknown, we examined these teeth to determine their efficacy in age prediction and also to compare their performance with that of canines.

The PTR of LI and PM1 did indeed have recognizably better correlation to age compared to that of the canine. This is similar to the results obtained in previous radiographic studies wherein *linear* measurements of canines showed lower age correlations than its neighboring teeth[6,27]; the results are also similar to another linear measurement-based study in-so-far as lateral incisor's higher correlation than the canine and first premolar is concerned.[19]

Cameriere et al.[13] believed that the size of the pulp area in canines revealed secondary dentinal deposition better than other teeth with smaller pulp areas (e.g., lateral incisor). The authors opined that the smaller size of such single-rooted teeth may lead to "less clear measurement" of the PTR (p. 1154).[13] In the present

Table 2
Regression coefficients and formulae for the lateral incisor, first premolar and various tooth combinations.

Tooth/tooth combination	*n*	*r*/*R*	Regression equation	S.E. (±years)
Lateral incisor	61	−0.395	Age = 60.703 + (−184.286 × PTR)	12.28
Canine	61	−0.206	Age = 55.888 + (−144.466 × PTR)	13.08
First premolar	61	−0.362	Age = 58.441 + (−169.436 × PTR)	12.45
All three teeth	61	−0.438	Age = 68.014 + (−36.743 × PTRC) + (−92.949 × PTRPM1) + (−128.898 × PTRLI)	12.22
Lateral incisor + Canine	61	−0.406	Age = 66.493 + (−71.21 × PTRC) + (−170.755 × PTRLI)	12.31
Lateral incisor + first premolar	61	−0.435	Age = 65.381 + (−100.579 × PTRPM1) + (−131.906 × PTRLI)	12.13
Canine + first premolar	61	−0.37	Age = 62.767 + (−56.945 × PTRC) + (−155.177 × PTRPM1)	12.52

study, however, we could not appreciate a translation of this potential disadvantage to poorer age correlation for lateral incisors vis-à-vis canines.

Taking multiple teeth did not markedly improve the PTR–age-correlation when compared to single teeth (Table 2). This contrasts with the results of Camereiere et al.,[12,13] where the use of maxillary and mandibular canines, in combination, produced higher age correlation as well as more accurate age estimates when compared to those teeth taken alone. It also differs from other radiographic studies which evaluated reduction in the pulp chamber and root canal. For example, Kvaal et al. (Table 5)[6] and Bosmans et al. (Table 4)[19] observed recognizably higher age correlations when the mandibular teeth were used in combination rather than alone.

Unsurprisingly, there was little difference in S.E.E.s ($\pm$12.13–13.08 years) between the various linear and multiple regression equations (Table 2). The errors exceeded $\pm$10 years irrespective of whether teeth were used alone or in combination, and was outside the "acceptable" range proposed by Solheim and Sundnes.[26]

These errors are in stark contrast to those derived using single or multiple teeth in Cameriere et al.,[12,13,15,17] which ranged between approximately $\pm$2.5–5 years. A possible reason for such low errors may be that they assessed teeth of the same class (i.e. maxillary and mandibular canines) and the radiographs obtained were taken particularly for these teeth (i.e., radiographs were made centering the canines). In contrast, the teeth evaluated in our study belonged to multiple classes and, moreover, the radiographs were not taken centering the lateral incisor and first premolar. However, this does not explain why the canine produced large errors ($\pm$13.08 years) when compared to the canine assessment of Cameriere et al.[12] A large error ($\sim\pm$11 years) was also noted for the canine in a bigger sample that we assessed previously.[16]

A more plausible explanation may be that most studies by Cameriere et al.[12,13,15,17] examined a skeletal sample wherein lack of facial soft-tissue may have rendered the radiographic images of teeth with greater clarity; in our sample, drawn from living individuals, superimposition of the facial soft tissue on to the teeth may have precluded optimal tooth and pulp canal visualization. In addition, population variability in the rate of secondary dentin deposition may also have contributed to the divergent results. Therefore, our evaluation of radiographs of living subjects, the ethnically different population group and the resulting low age correlation of secondary dentine deposition (Table 2), may have produced larger error rates in the present sample.

This indicates that radiographic evaluation of secondary dentine deposition in living adults may not produce accurate age estimates in Indians, and echoes the warning of Schmeling et al.[28] against the use of single tooth variables in age estimation. In fact, the S.E.E.s in our sample, which is $> \pm$10 years, can be equated with the "third best methods" of age estimation categorized by Schmeling et al. (p. 179).[28] Compounding the disadvantage of the large S.E.E.s is the significant observer differences (see "Results"), which may also owe to the poor contrast resulting from the presence of soft tissues. The issue of subjective nature of selecting the pulp and tooth area may need further exploration through more extensive repeat measurements.

The deficiencies described herein may point toward an inherent limitation to the PTR method's application in Indians. But, as stated by us before,[16] radiographic evaluation of secondary dentine may be the only *non-invasive* approach to estimate age from fully developed teeth. Hence, there may be few alternatives to dental age estimation of living adults as well as in certain post-mortem circumstances wherein invasive methods are not feasible. Although a recent study from India that examined a larger sample has produced more accurate estimates,[18] indicating that the method may be useful in Indians, it must be noted that this larger sample had a gross under-representation of middle and old age-groups (>44 year-olds constituted < 18% of the total sample size), thereby undermining its conclusions. It has been suggested that unequal distribution of subjects across diverse age-groups can give erratic results.[29] Hence, further scrutiny on larger samples with pan age-group representation from this country is necessary before making inferences on the method's appropriateness (or the lack of it) to this population.

5. Conclusion

The evaluation of the pulp/tooth area ratio of three mandibular teeth revealed that the lateral incisor had the highest correlation to age when used alone, followed by the first premolar and canine. The use of these teeth in various combinations did not result in recognizably higher correlation. More importantly, there were little practical differences in the accuracy of age estimates irrespective of whether single or multiple teeth were used, with S.E.E.s ranging between $\pm$12.1 and 13.1 years. These high errors are in contrast to previous studies and may be explained on account of the low-to-moderate age correlation of PTR in our Indian sample, as well as evaluation of a living subjects in the present study. Therefore, examination of secondary dentinal deposition on radiographs, specifically the PTR, for dental age estimation of living adults of Indian origin may need to be used carefully and judiciously, although further research on well-distributed age-groups in larger samples is warranted.

Conflict of interest

None.

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Ethical approval

Ethical approval was obtained from the Institutional Ethical Committee (Ethical Clearance dated 8th August 2008).

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